MANIPULATORS INCLUDING FORCE TRANSDUCER MEANS

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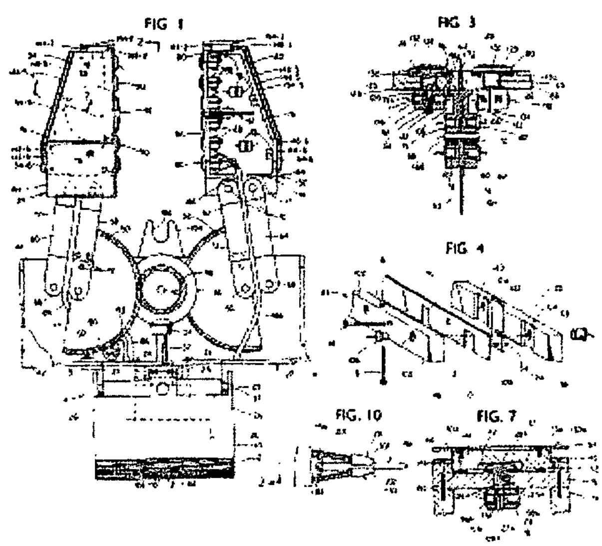
Abstract of **GB1470351**

1470351 Manipulator with force sensors STANFORD RESEARCH INSTITUTE 7 Jan 1975 636/75 Heading G1A A manipulator has jaws 29, 30 with object gripping faces and force transducer means, as 78, providing an electrical output, comprising vane 122 varying the amount of light reaching sensor 108 from source 106, biased by means 130, which is opposed by vane operating means 90, including moveable member 128 at the jaw face, when an external force is applied to it. The transducer means have body members 96, 98 with three pairs of aligned apertures 102, 104. Mask 109 with slots 110 limits the light beams. When vanes 122 move in grooves 120, slots 124 allow light to reach sensors 108. On removal of retaining pins 134, which limit motion, vanes 122 are removeable. Each means 90 has a body portion 125 with a flange 129 and a plastics or rubber gripping member 132 held in a recess in head 128. When a force acts on means 90, portion 125 slides in aperture 126 depressing vane 122. Biasing means 130 may be an elastomeric material or a metal or plastics spring and its stress/ displacement characteristic may be linear. It may Fig. 5 (not shown) have a triangular cross-section, so that the rate of deformation decreases with increased force. Transducer means 78, Fig. 7 is similar to 88, but the biasing means 130A is between wall 76 of plate 144, restrained in recess 150 by its flanges 146 against stop members 148 on wall 76. Soft rubber biasing means 157 is under head 128A. So long as external force is applied to cover plate 154 within the projected area of means 130A, the displacement of vane 122A is proportional to it. The sources maybe



L.E.D.s and the sensors phototransistors. A slip sensor 92, Fig. 3, comprises supporting members 160 attached to jaw wall 86 having elongated apertures 168 in which resilient biasing means 170 urge shaft 166 and its attached disc 164 outwardly. When an object is gripped between jaws 29, 30 disc 164 is urged inwardly. When slippage occurs a plurality of radial slits 174 in disc 164 pass between sources 176, 178 and sensors 180, 182, which are placed so that their outputs are 90 degrees out of phase. The number of pulses generated indicates the amount of slippage and the phase the direction. As in Figs. 1 and 10, the manipulator includes housing 16 for supporting jaws 29, 30 and a motor 25 for moving them and having brackets 194 with notches 196 receiving crosshead 200 of a T-shaped, handle of a tool 198, which has flats 202 gripped by the jaws.

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(54) MANIPULATORS INCLUDING FORCE TRANSDUCER MEANS

(71) We, STANFORD RESEARCH INSTITUTE, a corporation organised and existing under the laws of the State of California, United States of America, of Menlo Park, California 94025, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to manipulators.

Manipulators are widely used in scientific and industrial fields in a variety of applications, for instance in automated assembly lines, teleoperator systems, prosthetics and robots. They may be hand operated or power operated, e.g. hydraulically or electrically. Many such manipulators are constructed without any force sensing means whatsoever and consequently are operated without knowledge of the forces encountered in use. When force sensors or transducers are employed, they may be of the on-off (i.e. binary) or proportional type. The on-off type merely indicate that a force is applied to the manipulator without any indication of the magnitude thereof. Proportional sensors, such as strain gauges, are sometimes incorporated in the manipulator to provide an indication of the magnitude of the force. Strain gauges are often difficult to incorporate into the manipulator structure and are relatively expensive and unreliable in use because of the dead weight and acceleration loading experienced when the manipulator is in motion.

According to the present invention there is provided a manipulator which includes a pair of relatively movable jaws having opposing jaws faces between which an object may be gripped and force transducer means at a face of at least one jaw for providing an electrical output related to the force applied thereto, the force transducer means comprising means for forming a beam of light, a light sensor positioned to receive the light beam, a light vane movable in opposite directions across the path of the light beam to vary the amount of light which reaches the sensor in accordance with the position of the vane, means for resiliently biasing the vane in one said direction, and vane operating means connected to the vane and including a movable member at a jaw face for moving the vane in the direction opposite to said one direction against the action of the resilient biasing means upon application of an external force thereto.

In use, the resilient biasing means, which may be an elastomeric ring, or a spring, urges the vane in said one direction, and external forces on the movable member urge the vane in the opposite direction against the action of the resilient biasing means. The amount of light reaching the light sensor is related to the force applied to the movable member, and the photocell output provides a measure of such force. The transducer means is preferably of a sufficiently small size to permit a plurality of transducer means to be located on the manipulator. For example, a plurality of said movable members may be located on a single face of the manipulator, such as the gripping surface of a jaw, for sensing the gripping force at different places thereon. Also, in addition to the gripping surface, other surfaces of the manipulator may be provided with one or more of said movable members for sensing forces applied to the jaws from different directions. Each jaw may in fact be substantially covered with said movable members for sensing forces applied thereto from substantially any direction.

The resilient biasing means may be selected for desired elastic properties. The load deformation curve of the resilient biasing means may, within elastic limits thereof, be substantially linear, so that with suitable vane construction and selection of operating components, the transducer output from the light sensor may be made substan-

tially linear with the force applied. By use of a resilient biasing means having a non-uniform cross-sectional shape a nonlinear load deformation curve may be obtained to provide for a transducer having different operating characteristics. Because of the wide variety of resilient biasing means which may be employed, it will be apparent that a wide variety of transducer operating ranges and operating characteristics is possible.

In a preferred manipulator described in detail hereinbelow the jaws are provided with slip sensors, each of which comprises a rotatable disc extending from gripping face of the jaw. The discs are oriented in perpendicular planes which are mutually perpendicular to the opposing jaw faces and are mounted for radial movement to permit movement into the respective jaws when an object is gripped between the jaws. The discs are coded, as by the provision of alternate transparent and opaque areas thereon, and light emitting and light sensing means are located at opposite sides of the disc for sensing rotation thereof. With the above-mentioned orthogonal orientation of the discs in the jaw face or jaw faces, slippage of gripped objects in any direction in the plane parallel to the jaw faces is sensed. Such information could be used, for example, to increase the gripping force supplied by the jaws to stop such slippage.

The preferred manipulator includes means for supporting the jaws and tool holder means at said supporting means for engagement with a tool gripped between the jaws.

The invention will now be further described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a plan view of a manipulator embodying this invention and including a pair of relatively movable jaws, with portions of a jaw and jaw actuating mechanism removed and broken away, respectively, for clarity of illustration;

Figure 2 is a view taken along line 2—2 of Figure 1 showing a portion of the manipulator in cross-section;

Figure 3 is an enlarged view taken substantially along line 3—3 of Figure 2 showing force transducers and a slip sensor at one jaw;

Figure 4 is an enlarged fragmentary exploded view showing one of the force transducers employed in the manipulator;

Figure 5 is a view of a modifier form of resilient biasing means comprising a member having a triangular-shaped cross-section, which member may be used with any of the force transducers shown in the drawings;

Figure 6 is a compressive stress-strain diagram of the resilient biasing means shown in Figure 5;

Figure 7 is an enlarged fragmentary sectional view taken along line 7—7 of Figure 1 showing a transducer and transducer actuating mechanism at one wall of a jaw;

Figure 8 is a fragmentary side view of the slip sensor shown in Figure 1;

Figure 9 is a waveform diagram showing the slip sensor outputs;

Figure 10 is a fragmentary plan view of the manipulator showing a tool held thereby; and

Figure 11 is a side elevational view of the tool shown in Figure 10.

Reference is now made to Figure 1 of the drawings wherein a manipulator is shown as comprising a manipulator or arm section 10 which may be coupled by threads 12 to a robot, automated machinery, an earth, space or underwater vehicle, or the like (not shown) such as are presently in use. The manipulator section 10 is shown coupled through a wrist sensor, designated generally by reference numeral 14, to a gear box or housing 16 included in a hand of the manipulator. The wrist sensor 14 is disclosed and claimed in our copending U.K. Patent application No. 640/75 (Serial No. 1,470,352), to which reference should be made. For present purposes, it will be understood that the wrist sensor includes a ring 18, one side of which is secured to a base 22 of the housing 16 as by screws 24 extending through holes in the base into threaded holes in the ring to secure the base and ring together. A reversible motor 20 is secured with respect to the base 22 by means of screws 23 extending through threaded holes in a flange 25 on the base 22 of the housing 16 into holes in a base of the motor. Resilient coupling means 26, such as pads of rubber or other resilient material, are cemented or otherwise suitably secured between a forward face 27 of the arm section 10 and a rearward face 28 of the ring 18 to secure the ring 18 (with the attached housing 16 and motor 20) to the arm section 10. The resilient coupling means 26 are deformed upon transmission of forces therethrough, and sensors, not shown, located adjacent the resilient coupling means provide a measure of the transmitted forces and torques.

The reversible motor 20 serves to open and close a pair of jaws 29 and 30 through a suitable gear and linkage mechanism which now will be described. A shaft 32 of the motor extends through the ring 18 and an operture in the base 22 and into the housing 16. A pinion 34 at the forward end of the motor shaft 32 engages a pair of inwardly facing bevel gears 36 and 38 which are independently rotatably supported on a shaft 40 extending between upper and lower walls 42 and 44, respectively, of the housing 16, as seen in Figure 2. For clarity, an upper wall 42 of the housing 16, which wall is removable to facilitate assembly, is shown broken away in Figure 1. Attached to or

formed on the bevel gears 36 and 38 at the outer sides thereof are spur gears 46 and 48 which engage sector gears 50 and 52, respectively, for drive actuation thereof. The sector gears 50 and 52 are rotatably mounted on shafts 54 and 56, respectively, extending between the upper and lower walls 42 and 44 of the housing 16.

A first pair of parallel links 58 and 60 connect the jaw 29 to the housing 16, and a similar second pair of parallel links 62 and 64 connect the other jaw 30 to the housing. Within the housing 16 the links 58 and 62 are pivotally supported on the shafts 54 and 56 about which the sector gears 50 and 52 pivot. The links 60 and 64 are pivotally mounted on shafts 66 and 68 extending between the housing walls 42 and 44. Pins 70 connect the forward ends of the links 58, 60, 62 and 64 to the jaws 29 and 30. The inner links 58 and 62 are slotted to receive the sector gears 50 and 52, respectively, and screws 72 secure the links to the gears.

Operation of the jaws 29 and 30 between open and closed positions, although believed to be apparent, will now be briefly described. When the motor 20 is energized for rotation of the bevel gear 34, the meshing bevel gears 30 and 38 are counterrotated. The counterrotating gears 36 and 38 drive the sector gears 50 and 52 in opposite directions through the spur gears 46 and 48. The links 58 and 62 attached to the sector gears 50 and 52 are thereby counterpivoted for closing or opening of the jaws 29 and 30. The links 60 and 64, which are parallel to the driven links 58 and 62, respectively, maintain confronting faces of the jaws 29, 30 in parallel relation.

The jaws 29 and 30, together with electromechanical transducer means for force and slip sensing, will now be described. Bodies or frames 74 of the pair of jaws 29 and 30 are of substantially identical construction and, as viewed from above as in Figure 1, each include a generally rectangular proximal end and a truncated pyramidal distal end. The jaw bodies 74 are hollow and have removable top and bottom walls 76 (the top wall of the jaw 30 being shown removed in Figure 1). 8he top and bottom walls 76 are mirror images of one another, but are identified with the same reference numeral for clarity. The rear ends of the removable walls 76 overhang a rear wall 77 of the frame 74 and provide support for the pins 70 connecting the forward ends of the parallel links 58, 60, 62 and 64 to the jaws 29 and 30. Two proportional force transducer means 78 are shown attached to the inside of each of the removable top and bottom walls 76, as seen in Figure 1. Similarly, proportional face transducer means 78 are attached to a forward wall 80, to an inclined outer wall 82 at the distal jaw end, and to an outer wall portion 84 at the proximal jaws end.

Inner facing walls 86 of the jaws 29 and 30 are shown provided with a plurality of transducer means 88 which are of similar design to the transducer means 78 at the other walls of the jaws. In the illustrated arrangement there is provided a 3 × 6 array of transducer actuating means, such as buttons, 90 for the transducer means 88 at the inner jaw faces, whereby the force applied at the 18 separate locations on each of the jaw walls 86 may be sensed. Also, located within the jaws are slip sensors 92 of identical design but differently oriented for sensing object slip transversely and longitudinally of the jaw faces, which sensors are described in greater detail hereinbelow.

The proportional force transducer means 78 and 88 will now be described. Two transducer means 88 are shown in the fragmentary sectional view of Figure 3, and an enlarged fragmentary exploded view of one is shown in Figure 4, to which figures reference is now made. Each transducer means 88 includes a pair of body members 96 and 98 having axially aligned apertures 102 and 104, respectively, extending therethrough. There are in fact three such pairs of axially aligned apertures 102 and 104 in the body members 96 and 98 for the support of three force sensing means. A light source 106, such as a light emitting diode, frictionally fits within the aperture 102, and a light sensor 108, such as a phototransistor, frictionally fits within the aperture 104 to receive light from the source 106. The apertures 102 and 104 are cylindrical to receive the light source 106 and light sensor means 108, which are also cylindrical. An aperture plate or mask 109 is sandwiched between the body members 96 and 98, which plate is formed with rectangular apertures or slots 110 positioned along axes 112 of light beams from the sources 106 to limit the light beams to a generally rectangular cross sectional shape. The body members 96 and 98 and aperture plate 109 are secured together as by screws 114 extending through holes in the body member 96 and aperture plate 109 and engaging threaded holes in the body member 98. Also, holes 116 may be formed in the body members 96 and 98 to accommodate screw fastening means 118 for securing the force transducers 88 to the manipulator jaws 29 and 30. Obviously, other mounting means, such as straps which extend across the transducers 88 and which are secured to the jaws 29 and 30, may be used to secure the transducers 88 to the jaws.

The body member 98 is shown formed with slots or grooves 120 which extend transversely of the apertures 104 from the top to the bottom of the body member. Each groove 120 accommodates a light vane 122

which is slidably movable therewithin in a direction transverse to the associated light beam axis 112. An elongate, rectangular light transmitting slot or aperture 124 is formed in the vane 122 and extends generally perpendicular to a slot 110 in the aperture plate 109. It will be apparent that a variable portion of the light beam from the source 106 may reach the light sensor 108, with the amount of light depending upon the position of the movable light vane 122. In the illustrated arrangement, the light from the source 106 is substantially totally blocked when the light vane 122 is in a normal, raised position, and an increasing amount of light is transmitted to the light sensor 108 as the light vane is moved inwardly. The current output from the light sensor 108 increases directly with an increase in the light received thereby.

An operating mechanism for actuation of the movable light vanes 122 includes the operating members or buttons 90 at the gripping surfaces of the jaws 29 and 30. As seen in Figure 3, the operating members 90 each comprise a cylindrical body portion 125 axially slidably movable within apertures 126 in the walls 86 at the operating faces of the jaws 29 and 30. The light vanes 122 are formed on or attached to the bodies 125 for movement therewith.

Each of the operating members 90 includes a head 128 comprising a radial flange 129 on the body portion 125. The outer ends of the apertures 126 are recessed to receive a resilient biasing means 130 between the head 128 and bottom of the recess for resiliently biasing the operating members 90 outwardly from the outer face of the wall 86. Gripping members 132 of plastics, rubber, or other material having a high coefficient of friction with respect to items to be gripped may be employed at the faces of the heads 128 to increase the gripping power of the jaws 29 and 30. In the illustrated arrangement the gripping members 132 comprise resilient discs carried within recesses within the heads 128 and extending from the faces thereof. A retaining and stop pin 134 extends through an extension of each vane 122 inside the jaw 29 or 30 and is engageable with the transducer body to retain the vane and operating means in operative position as illustrated.

Normally, in the undepressed condition of the operating members 90, the resilient biasing means 130 urges the light vane 122 outwardly, which movement is limited by engagement of the pin 134 with the transducer body. In this unactuated condition, the aperture 124 in the vane 122 is positioned to block substantially all light from the light source 106 from reaching the light sensor 108. When the actuating means 90 is depressed by application of an inwardly directed force thereon, the vane 122 is moved across the light beam axis 112 to allow light from the source 106 to reach the sensor 108. Within the elastic limit of the resilient biasing means 130, the distance through which the vane 122 is moved when the operating means 90 is depressed is directly related to the inward force on the operating means. Also, with the illustrated rectangular slots or apertures 110 and 124 in the aperture plate 109 and vane 122, respectively, the amount of light passing therethrough to the sensor 108 is directly related to the operating force.

The resilient biasing means 130 may each comprise a ring of elastomeric material such as natural or synthetic rubber or plastics. Alternatively, a metallic or plastics spring member may be employed. Such materials may exhibit a substantially linear compressive stress-strain characteristic within the elastic limits therof, within which limits the transducers may operate. Obviously, the invention is not limited to operation along only a linear portion of the compressive stress-strain characteristic of the resilient biasing means 130.

With the present arrangement the removal and replacement of a resilient biasing means 130 are easily accomplished by simply removing the retaining pins 134 for release of the actuating means. To extend the operating range and/or alter the operating characteristics of the transducers, resilient biasing means 130 with a different cross sectional shape, or formed as a composite unit from elements having different elastomeric properties, may be used. In Figure 5, for example, a resilient biasing means 136 in the form of a ring having a triangular cross-sectional shape is shown. A compressive stress-strain diagram for the member 136 is shown in Figure 6 in which greater deformation is experienced per unit force during initial application of a compressive force, which rate of deformation decreases with increased force. Further, conventional "O" rings which are commercially available in a wide variety of sizes and properties may be used.

The transducer means 78 are of substantially the same design as the transducer means 88 described above. Reference is made to Figure 7 wherein a transducer means 78 is shown as comprising body members 96A and 98A, an aperture plate or mask 109A sandwiched therebetween, a movable light vane 122A attached to the body portion 125A of the operating member extending through an aperture 126A in the removable wall 76, resilient biasing means 130A between a movable actuating plate 144 and the wall 76, and a light source 106 and light sensor 108 mounted in the members 96A and 98A. The head 128A is positioned in a recess 142 formed on the inner surface

of the movable actuating plate 144 at the geometric center of the resilient biasing means 130A. Outwardly extending flanges 146 are formed at opposite edges of the plate 144, and overlying stop or restraining members 148 attached to the wall 76 limit outward movement of the plate. The flanged area of the plate 144 is movable within a recess 150 formed at the outer surface of the wall 76. Screws 152 which extend through the stop members 148 and wall 76 fixedly secure the same to the jaw body 74. A cover plate 154 is attached by screws 156 to the actuating plate 144. A lightweight resilient biasing means 157, which may be of soft rubber, is positioned between the head 128A and the wall 76 to return the vane 122A to the raised position to block light from the source 106 to the sensor 108 when the actuating plate 144 is in the undepressed condition. With this arrangement the light vane 122A and associated operating means are maintained in position without the need for a retaining pin such as the pin 134 used in the transducer means 88 described above.

The force transducer means 78 at other locations on the jaws 29 and 30 are of the same generic design, except that the size and shape of the actuating plate 144, restraining members 148, and cover plate 154 conform to the size and shape of the wall portion at which the transducer means are located. For purposes of identification, these similar parts are supplied with the same reference numerals followed by a postnumeral for distinguishing between the same, such as 144—1, 144—2, etc., 148—1, 148—2, etc., and 154—1, 154—2, etc.

Normally, in the undepressed condition of the actuating plate 144 the resilient biasing means 130A urges the plate 144 outwardly into engagement with the restraining means 148, and the soft resilient biasing means 157 urges the head 128A of the operating member into the recess 142 in the plate 144. In this unactuated condition the aperture 124A in the vane 122A is positioned to block substantially all light from the source 106 to the light sensor 108. If an actuating force is applied directly above the head 128A of the operating member, the plate 144 and attached cover plate 154 are moved linearly in the direction of movement of the vane 122, evenly compressing the resilient biasing means 130A (and 157) along its entire length. If the force is not applied directly over the head 128A, but is applied within the projected area of the resilient biasing means 130A, the plate 144 is tilted and the resilient biasing means 130A is compressed to a greater extent where the force is most directly applied. In either case, for the same actuating force on the plate 144, the vane 122A is moved the same distance. Consequently, within the elastic limit of the resilient biasing means 130A, the distance which the vane 122A is moved when the plate 144 is depressed is directly related to the inward force thereon. As with the biasing means 130, the resilient biasing means 130A are easily removed and replaced when desired to provide the transducer 78 with the desired operating characteristics and/or operating range.

A description of the slip sensors 92 now will be given. As noted above, the slip sensors 92 in the jaws 29 and 30 are of identical design but are oriented differently for sensing slip of a gripped object in any direction in a plane extending parallel to the gripping surfaces of the jaws. To facilitate such mounting of the slip sensors 92 within the jaw bodies, the transducer means 88 are oriented longitudinally within the jaw 29 (as seen in broken lines in Figure 1) and transversely within the jaw 30. As shown in Figures 3 and 8, the slip sensor 92 comprises a pair of supporting members 160 attached to the jaw wall 86 in mutually spaced relationship as by screw fasteners 162. A disc 164, which functions as a combination motion sensing and code wheel, is attached to a shaft 166 rotatably mounted between the members 160. The shaft 166 is supported within elongate apertures 168 in the members 160, and resilient biasing means 170, such as elastomeric members, at the inner end of the apertures urge the shaft and attached disc 164 radially outwardly for protrusion of the disc from the gripping surface of the associated jaw 29 or 30 through a slot 172. It will be apparent that when an object is gripped between the jaws, the discs 164 are urged inwardly against the action of the resilient biasing means 170. Each disc 164, of course, remains rotatably mounted regardless of its radial position. Other means, such as springs acting on bearings supporting the shaft 166, may be used to bias the disc 164 in place of the elastomeric members 170.

The disc 164 may be coded, for example by providing it with a series of radially extending light transmitting areas, such as elongate slots 174 extending therethrough, separated by opaque areas. In the illustrated arrangement, for reasons which will become apparent hereinbelow, an odd number of slots 174 are employed. The supporting members 160 have axially aligned apertures therein at diametrically opposite locations opposite the ends of the elongate mounting apertures 168 for the support of light emitting means 176 and 178 and light sensing means 180 and 182, respectively, at opposite sides of the disc 164 adjacent the apertures 174. Light from a light emitting means 176, 178 passes through the apertures 174 when the apertures are aligned with the light beam axes for illumination of the light

sensing means 180, 182. Radial movement of the disc 164 when gripping an object has substantially no effect on electrical outputs of the light sensing means 180, 182 because of the elongate nature of the apertures 174 and the positioning of the light emitting means and sensing means relative thereto.

If slippage of an object gripped by the jaws 29 and 30 occurs, one or both of the slip sensor discs 164 at the opposite jaws will be rotated depending upon the direction of slippage relative thereto. As a disc 164 is rotated, variable outputs are produced at the sensing means 180 and 182, these outputs being shown as waveforms 180A and 182A in the diagram of Figure 9. The sensing means 180 and 182 are spaced around the centre ot the disc 164 so that the output from one leads or lags that from the other by approximately 90 degrees. In the waveform diagram of Figure 9, a waveform depicting the sum of the output voltages from the two sensing means 180 and 182 is identified by reference number 184. With a knowledge of the diameter of the disc 164 and the number of apertures 174 formed therein, it will be apparent that any of the signals 180A, 182A or 184 may be converted into pulses, with the number of pulses being indicative of the amount of slippage. Also, it will be apparent that the phase of the two signals 180A and 182A is indicative of the direction of slippage, i.e., direction of rotation of the disc 164. This information as to direction and amount of rotation produced by slippage of an object between the jaws may be conveyed to any desired utilization means (not shown).

Leads to and from the slip sensors 92 and force transducers 78 and 88 within the jaws 29 and 30 may be incorporated in a cable, as identified by the reference numeral 186 in Figure 1, and fed from the jaws to the housing 16. Indication of the relative position ofthe jaws 29 and 30 may be provided by means of a potentiometer 190 attached by screws 192 to the base 22 of the housing 16 and coupled through a spur gear 193 to one of the sector gears 50. The poteniometer setting is directly related to the relative jaw position, and leads (not shown) from the potentiometer 190 also may be extended back through the arm section 10 for connection to a suitable utilization circuit. The various force, slip and position signals provided by the manipulator may be used for indication and/or control purposes, as will be well understood by those skilled in this art.

To lend added versatility to the manipulator, the hand may be provided with tool holding means comprising brackets 194 extending from the forward top and bottom edges of the housing 16. The forward ends of the brackets are slotted or notched as at 196 to receive across head 200 of a T-shaped handle of a tool 198 shown in Figures 10 and 11. The cross head 200 of the tool 198 fits within the slots or notches 196 and a shank of the tool has flats 202 along opposite sides thereof which may be tightly gripped between the jaws 29 and 30. For purposes of illustration, the tool 198 is shown provided with a screwdriver blade at its forward end. A switch (not shown) may be included at the base of a notch 196 to indicate that the T-handle is firmly seated and that the tool 198 can be grasped. The inside jaw force sensors 88 signal when proper grasp has been achieved. With the illustrated arrangement, the tool is tightly held and may be subjected to large forces and torques without slippage.

A preferred embodiment of the invention having been described in detail by way of example, various changes and modifications following within the scope of the invention will suggest themselves to those skilled in this art. For example, the proportional force transducers may be modified for location of the resilient biasing means at a different location in the structure. Also, tension rather than compression type resilient biasing means may be used. In addition, the light vane may be arranged to block light to the light sensor rather than to admit more light thereto upon actuation of the transducer. Also, complete blockage of light by the light vane is not required since the utilization circuit to which the light sensor outputs are connected may be arranged to electrically compensate for output potentials present in the absence of an actuation force being applied to the transducers. Also, only one manipulator jaw need be movable, and both slip sensors could be located in a single jaw. Furthermore, the force transducers may be used without the slip sensors, and slip sensors used without the force transducers. In addition, force transducers need not be located at every face of the jaws, or employed in the numbers illustrated.

WHAT WE CLAIM IS:—

1. A manipulator which includes a pair of relatively movable jaws having opposing jaw faces between which an object may be gripped, and force transducer means at a face of at least one jaw for providing an electrical output related to the force applied thereto, the force transducer means comprising means for forming a beam of light, a light sensor positioned to receive the light beam, a light vane movable in opposite directions across the path of the light beam to vary the amount of light which reaches the sensor in accordance with the position of the vane, means for resiliently biasing the vane in one said direction, and vane operat-

ing means connected to the vane and including a movable member at a jaw face for moving the vane in the direction opposite to said one direction against the action of the resilient biasing means upon application of an external force thereto.

2. A manipulator according to claim 1, wherein the vane operating means is located at one of said opposing jaw faces for sensing the force with which an object is gripped thereby.

3. A manipulator according to claim 2, which includes a plurality of said force transducer means and a plurality of associated vane operating means at said one of said opposing jaws faces for individually sensing forces applied at different locations of said one jaw face.

4. A manipulator according to claim 2 or claim 3, which includes a plurality of said force transducer means and a plurality of associated vane operating means at other jaw surfaces for individually sensing forces applied to said other jaw surfaces.

5. A manipulator according to any one of the preceding claims, wherein the means for forming a beam of light includes a light emitting diode, and the light sensor comprises a phototransistor.

6. A manipulator according to any one of the preceding claims, wherein the vane is arranged to substantially totally block the light beam in the unactuated condition of the vane operating means.

7. A manipulator according to any one of claims 1 to 6, wherein, in use, the amount of light reaching the light sensor is substantially directly proportional to the force applied to the movable member of the vane operating means.

8. A manipulator according to any one of claims 1 to 6, wherein the resilient biasing means comprises a member having a triangular cross section to provide a nonlinear force at the vane operating means versus vane movement characteristic.

9. A manipulator according to any one of the preceding claims, including removable limiting means for limiting movement of the vane operating means in said one direction, the resilient vane biasing means being removable for replacement upon removal of the removable limiting means.

10. A manipulator according to any one of the preceding claims, including slip sensor means at at least one of the opposing jaw faces for sensing slippage of an object gripped between said jaws.

11. A manipulator according to claim 10, wherein the slip sensor means is arranged for sensing slippage of a gripped object in first and second orthogonal directions along the opposed jaw faces.

12. A manipulator according to claim 10 or claim 11, wherein the slip sensor means comprises a member which is rotatable by slippage of an object between the jaws.

13. A manipulator according to claim 12, wherein the rotatable member extends from said one opposing jaw face to engage an object gripped between the jaws.

14. A manipulator according to claim 13, wherein the jaws are hollow and include walls which include the opposing jaw faces, and said rotatable member extends through an aperture in one of said walls.

15. A manipulator according to claim 13 or claim 14, wherein the rotatable member is mounted for translational movement into the jaw from which it extends by engagement with a gripped object.

16. A manipulator according to any one of claims 12 to 15, wherein the rotatable member is a disc.

17. A manipulator according to claim 16, when claim 16 is appendant to claim 11, wherein the slip sensor means includes a pair of said discs which are orthogonally oriented.

18. A manipulator according to claim 16 or claim 17, including means with an electrical output for sensing rotation of the disc.

19. A manipulator according to claim 18, wherein the rotation sensing means includes code means on the disc.

20. A manipulator according to claim 16, claim 17 or claim 18, wherein the disc is formed with an alternating series of radially extending light opaque and light transmissive sections arranged around the axis of the disc, and light emitting means and light sensing means are arranged at opposite sides of the disc so that light passing therebetween passes through a light transmissive section of the disc for detecting rotation thereof by reason of a variable amount of light reaching the light sensing means as the disc is rotated.

21. A manipulator according to claim 20, as appendant to claim 15, wherein the light emitting and light sensing means include first and second pairs of light source and light detecting means generally diametrically oppositely located in the direction of translational movement of the disc.

22. A manipulator according to any one of the preceding claims, including means for supporting the jaws, and tool holder means at said supporting means for engagement with a tool gripped between the jaws.

23. A manipulator according to claim 22, wherein the tool holder means is formed with a notch to receive a head of an elongate tool grasped between the manipulator jaws to prevent rotation of the grasped tool when the tool is subjected to torque about its longitudinal axis.

24. A manipulator according to any one of claims 1 to 21, including a housing, res-

pective means for mounting the jaws on the housing for relative pivotal movement for grasping objects therebetween, a motor attached to said housing and connected to the jaws for relatively pivotally moving the jaws and tool holder means attached to said housing intermediate the jaw mounting means and arranged for engagement with an end of a tool to be grasped between the jaws.

25. A manipulator according to claim 24, wherein the tool holder means includes brackets extending from the housing towards the jaws, the brackets being formed with notches at ends thereof remote from the housing to receive the head of a tool.

26. A manipulator according to claim 25, including a tool having a shank capable of being grasped by the jaws and a cross head engageable with the notches in the brackets.

27. A manipulator according to claim 26, wherein said shank is formed with oppositely disposed flats for grasping between the jaws.

28. A manipulator substantially as herein described with reference to Figures 1 to 4 and 7 to 10 of the accompanying drawings.

29. A manipulator substantially as herein described with reference to Figures 1 to 4 and 7 to 10 of the accompanying drawings, as modified by Figures 5 and 6.

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1470351 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

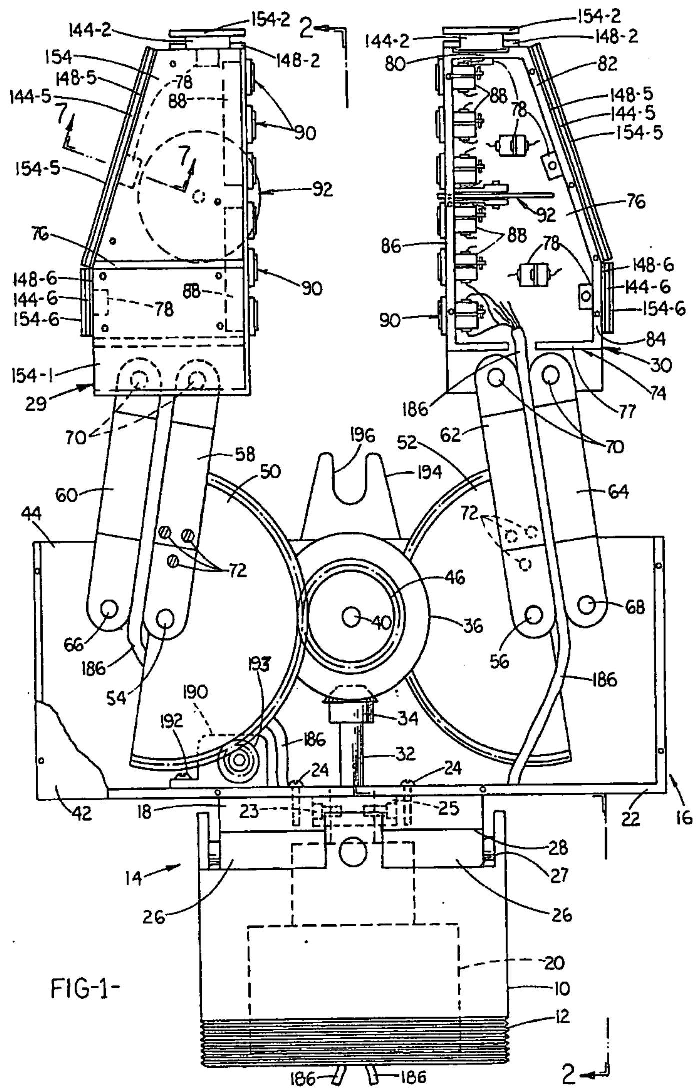

FIG-1-

1470351 COMPLETE SPECIFICATION

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Sheet 2

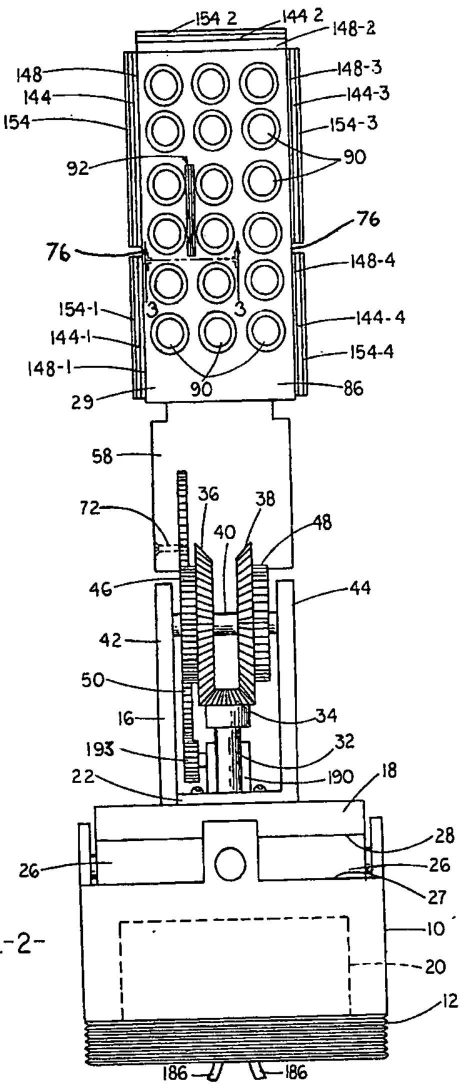

FIG.-2-

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Sheet 3

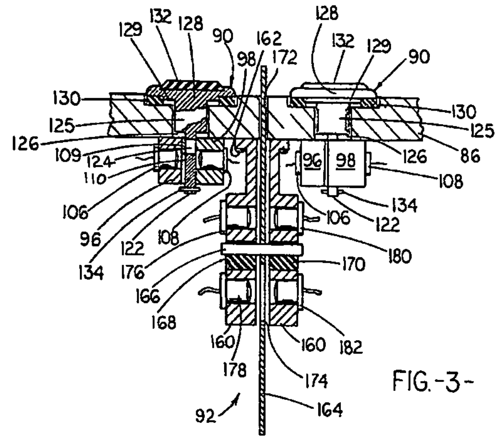

FIG.-3-

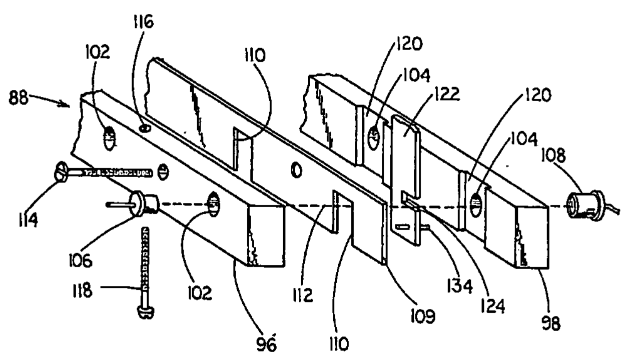

FIG.-4-

FIG.-5-

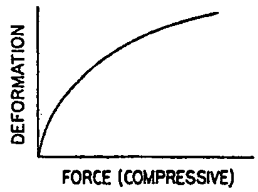

FIG.-6-

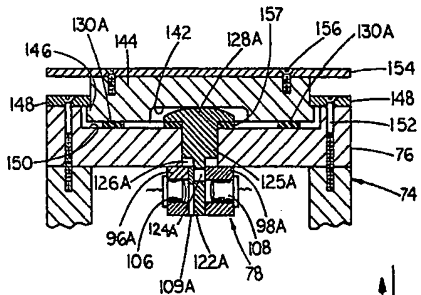

FIG.-7-

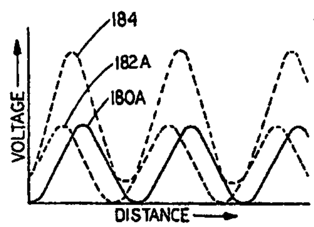

FIG.-9-

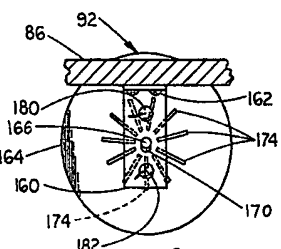

FIG.-8-

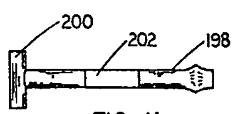

FIG.-11-

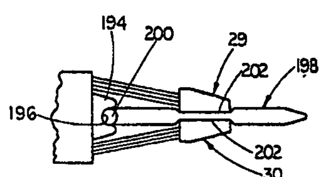

FIG.-10-